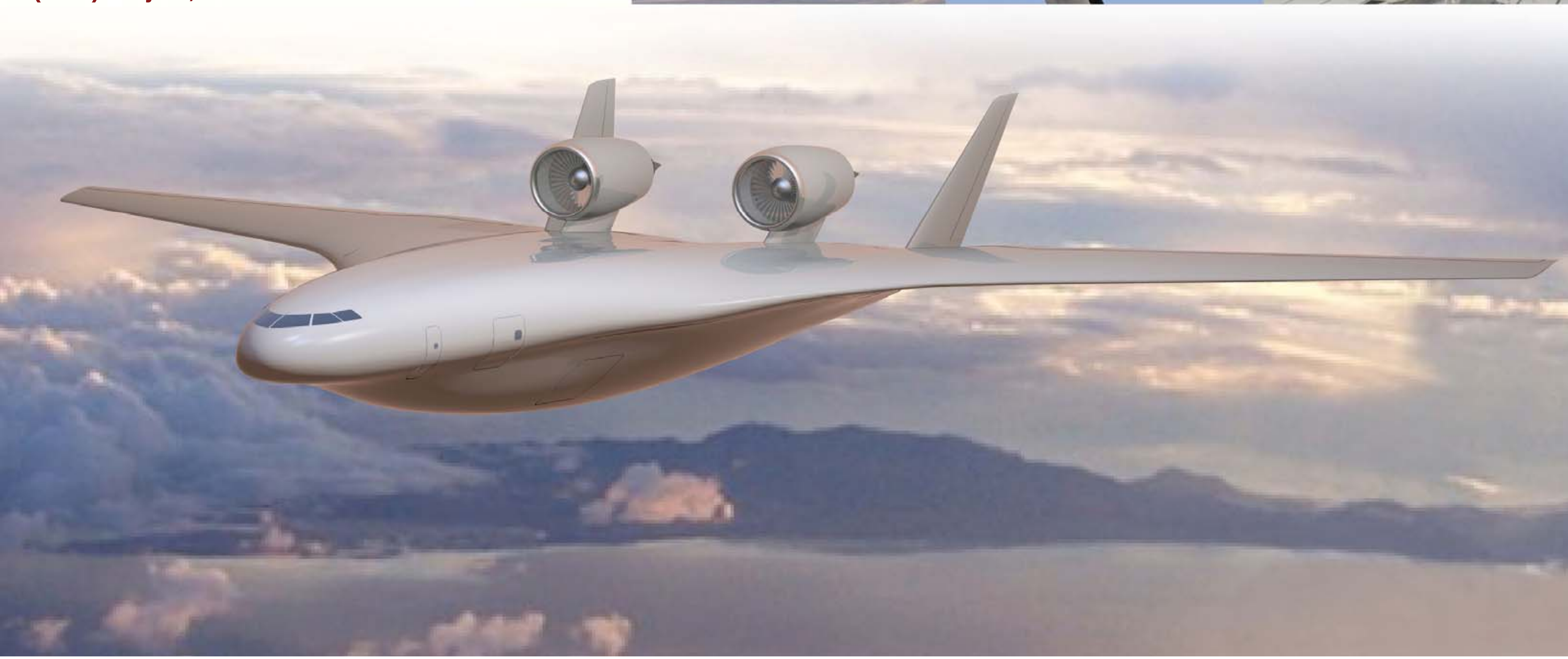
National Aeronautics and Space Administration

Environmentally Responsible Aviation (ERA) Project

Assessing Progress Toward Simultaneous Reductions in Noise, Fuel Burn and NOx

Craig Nickol
VSI Systems Analysis Element Lead
Environmentally Responsible Aviation (ERA) Project, NASA



Topics Addressed

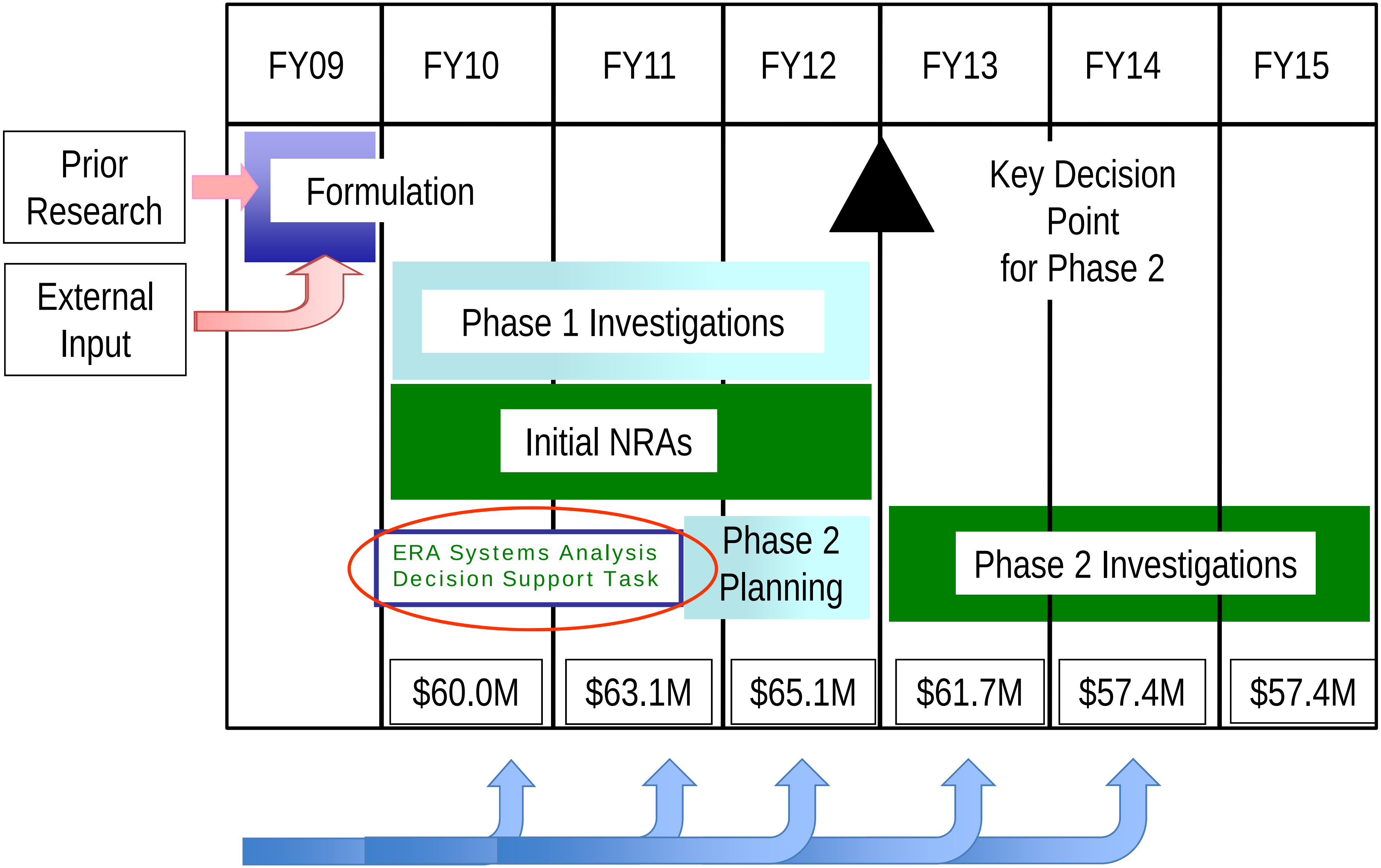
- ERA Project Metrics Evolution

- ERA Portfolio Analysis Status

  Measuring Progress Towards our Goal

  (Top down and Bottoms Up)

ERA Project Overview, Flow And Key Decision Point for Phase 2



Technical input from Fundamental Programs, NRAs, Industry, Academia, Other Gov't Agencies

ERA Goals, Objectives & System Level Metrics

ERA Goal

	N+1 = 2015** Technology Benefits Relative To a Single Aisle Reference Configuration	N+2 = 2020** Technology Benefits Relative To a Large Twin Aisle Reference Configuration	N+3 = 2025** Technology Benefits
Noise (cum below Stage 4)	-32 dB	-42 dB	-71 dB
LTO NO_x Emissions (below CAEP 6)	-60%	-75%	better than -75%
Performance: Aircraft Fuel Burn	-33%	-50%	better than -70%
Performance: Field Length	-33%	-50%	exploit metro-plex* concepts

**Technology Readiness Level for key technologies = 4-6. ERA will undertake a time phased approach, TRL 6 by 2015 for “long-pole” technologies
*   Concepts that enable optimal use of runways at multiple airports within the metropolitan area

In 2005, market opportunities drove the development of the system level metrics

- The market was predicting there would be a single aisle (B737/A320) replacement aircraft by 2015*
  - This drove the N+1 focus and metrics to be referenced to SOA single aisle

- Also, we projected about 10 years later there would be a large twin aisle (B777) replacement
  - This drove the the N+2 focus, and metrics to be referenced to the SOA large twin aisle

*Chinese C919, 168-190 seat class and Russian MC-21, 150-212 seat class First Flights in 2014?

Market Opportunities - Current Forecast

- Beyond 2015, before 2020 – New engines (GTF, LEAP-X)
  - A320 New Engine Option
  - Re-engine B737?

- Beyond 2020, before 2025 – CONVENTIONAL THINKING
  - Single Aisle Replacement (B737/A320)
    - High probability tube and wing, adv engine (open rotor)/combustors, advanced structures, plus laminar flow
  - Large Twin Aisle Replacement (B777, etc)
    - High probability tube and wing, advanced engine/combustors, advanced structures, laminar flow, but HWB likely to be evaluated as serious contender

- 2025 and BEYOND – UNCONVENTIONAL THINKING – WHAT IF REPLACEMENTS SLIP TO RIGHT?
  - NASA N+2 and N+3 studies identifying key, time-phased technology roadmaps, and “system ready” unconventional configurations
    - Joined wing, trussed braced wing, double bubble, HWB, etc.
    - Hybrid/JP8/battery, cryo-cooling, low energy nuclear reactors, etc….

Assess impacts of technology investments on market opportunities

2010 Assessment | Re-engine/Retrofits | Replacement Conventional | Replacement Unconventional
2010 Assessment | Re-engine/Retrofits | Replacement Conventional | Replacement Unconventional
2010 Assessment | Re-engine/Retrofits | Replacement Conventional | Replacement Unconventional
2010 Assessment | Re-engine/Retrofits | Replacement Conventional | Replacement Unconventional

2010 Assessment Very Large	Re-engine/Retrofits	Replacement Conventional	Replacement Unconventional
Noise (cum below Stage 4)			
LTO NO_x Emissions (below CAEP 6)			
Performance: Aircraft Fuel Burn			
TIME NOW →			→ 2025 +

ERA Systems Analysis Overview

ERA systems analysis tasks for measuring progress towards our goal

- "Top Down" Methodology Overview
- Concept Modeling Results Summary
- Large Twin Aisle Class Advanced Tube + Wing and HWB

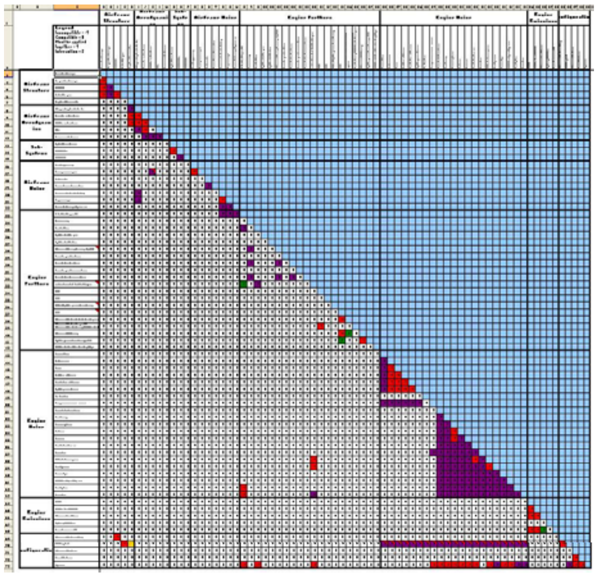
Georgia Tech's Aerospace Systems Design Lab (ASDL) is supporting ERA to perform this analysis

ERA N+2 Technology Database

(3rd Iteration Completed August 2010)

ERA Technology Database Development Approach:

- Multiple Data Sources:
  - ➢ ERA Phase 1 Project Plans
  - ➢ GA Tech JPDO/FAA EDS Database
  - ➢ NASA N+3 NRA Reports
  - ➢ FAP/SFW Planning Reports
  - ➢ ERA Project Engineers
  - ➢ ERA Discipline Experts
- Technologies with TRL too low or too high for ERA were removed



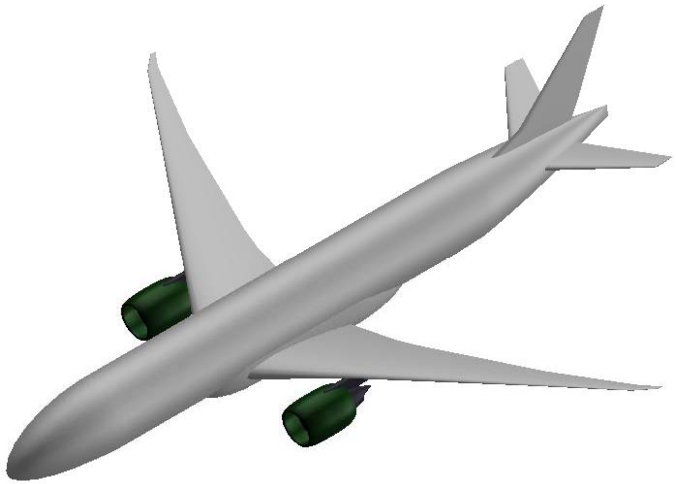
Technology Compatibility Matrix
Shows Interactions for 65 Technologies

Technology Database Analysis Report includes:

- Technology Description
- Current and Projected TRLs
- Technology Compatibility Matrix (interactions for 65 Technologies
- Summary Spreadsheet (19 airframe technologies; 46 engine technologies)
- Projected benefits and impacts
- Modeling approach in EDS

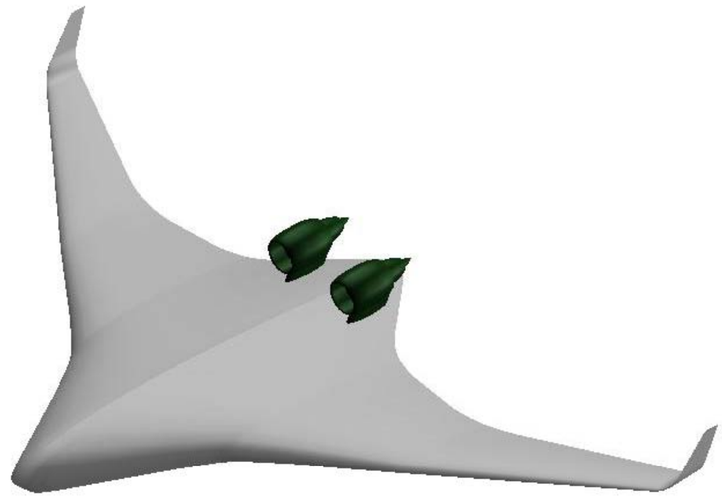
Initial Technology "Collectors"

Advanced Tube and Wing



Engine Options:
Advanced direct drive
Geared Turbofan
Open Rotor

Hybrid Wing Body



- **Potential ERA airframe and engine technology packages installed on both conventional and advanced configurations**

- **Fuel burn, noise and emissions are estimated using models developed in NASA's standard toolset (NPSS/WATE, FLOPS, ANOPP) which has been integrated into Ga Tech's Environmental Design Space (EDS) tool**

- **EDS can feed global tools in AEDT for fleet level global impact estimates**

- **Seeking additional technology collector advanced configurations through NRA and in-house efforts**

Technology Rankings

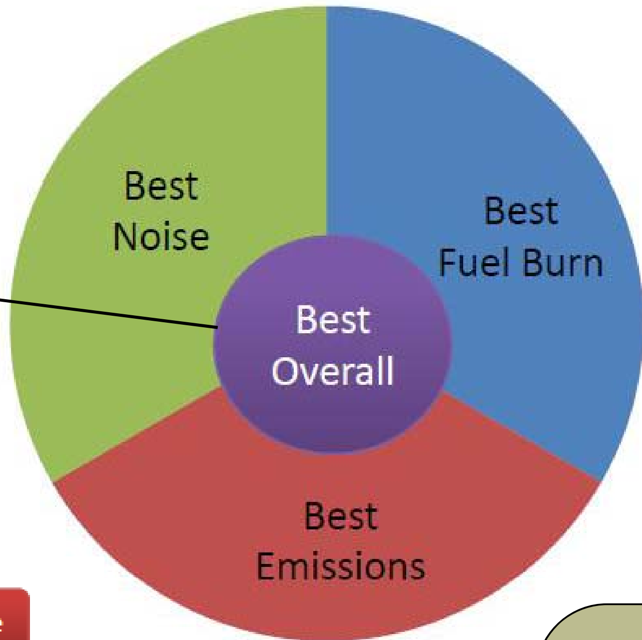
- Both deterministic and probabilistic assessments will be performed to determine the ERA technology package that results in the best overall performance (probabilistic assessment will provide a quantified confidence level)

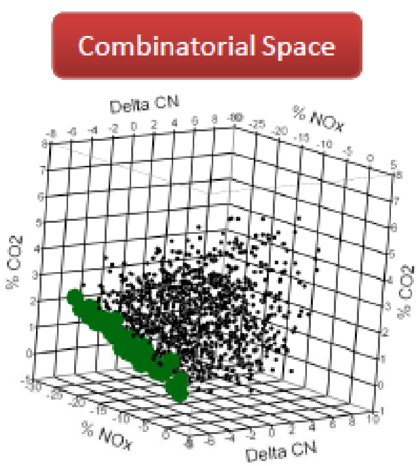
<u>**Product**</u>

Recommendations for ERA Phase II Portfolio:

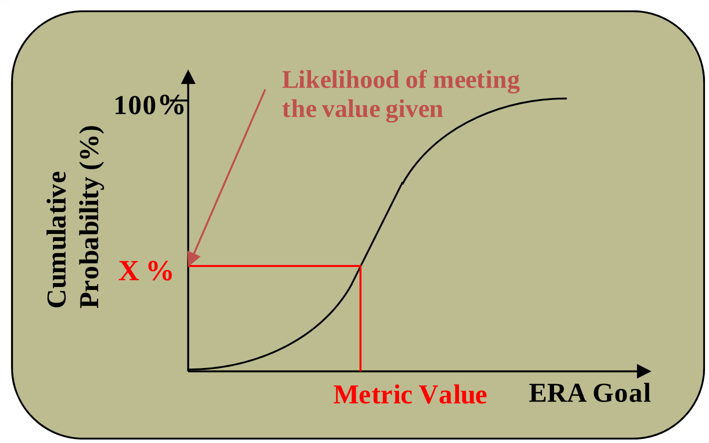
Technology Package for Best Overall Performance:

Airframe Tech 1
Airframe Tech 2
Airframe Tech 3
Engine Tech 1
Engine Tech 2
Engine Tech 3
…





Deterministic – Cloud of Point Solutions

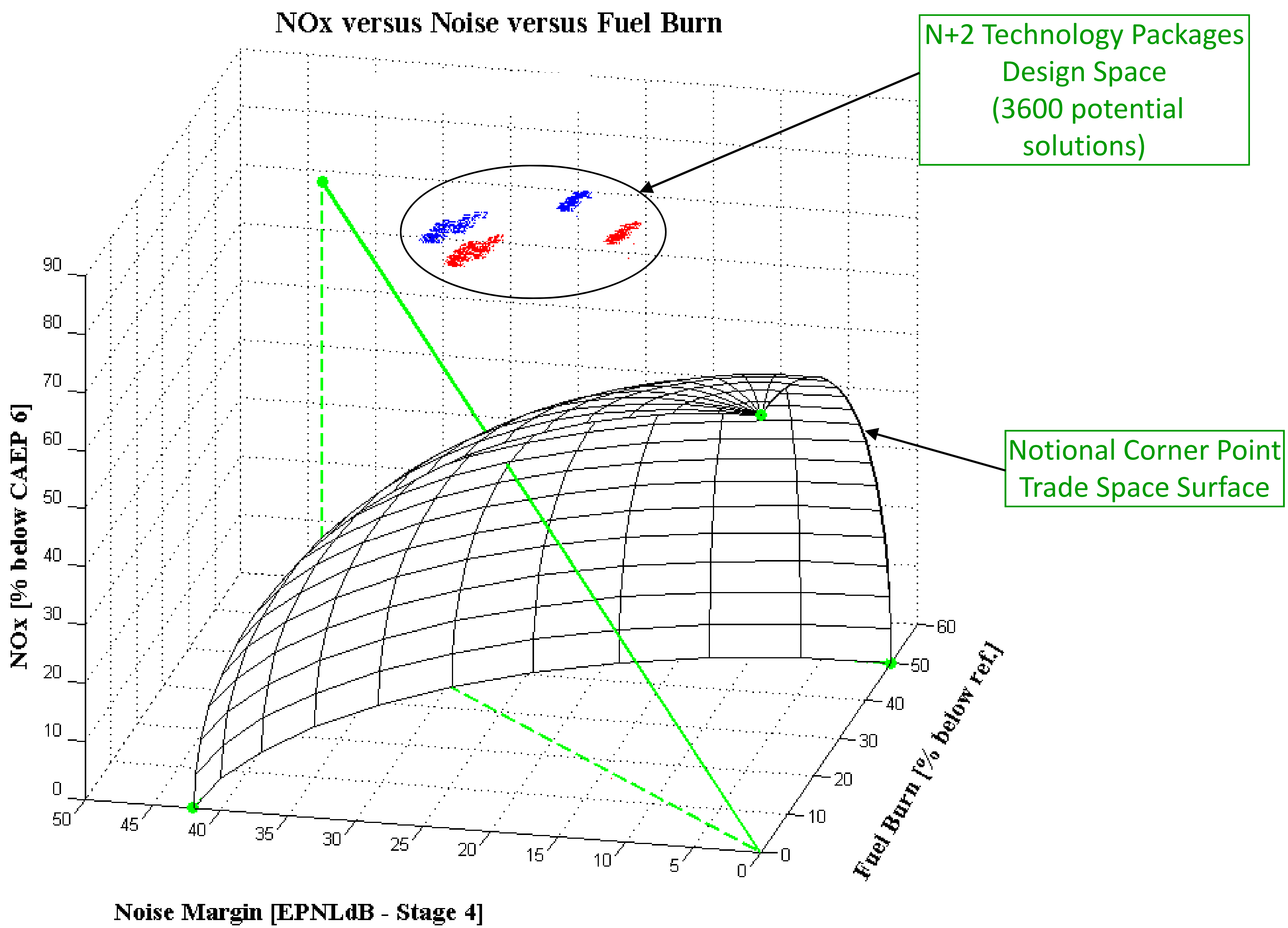


Probabilistic – Confidence in meeting a metric

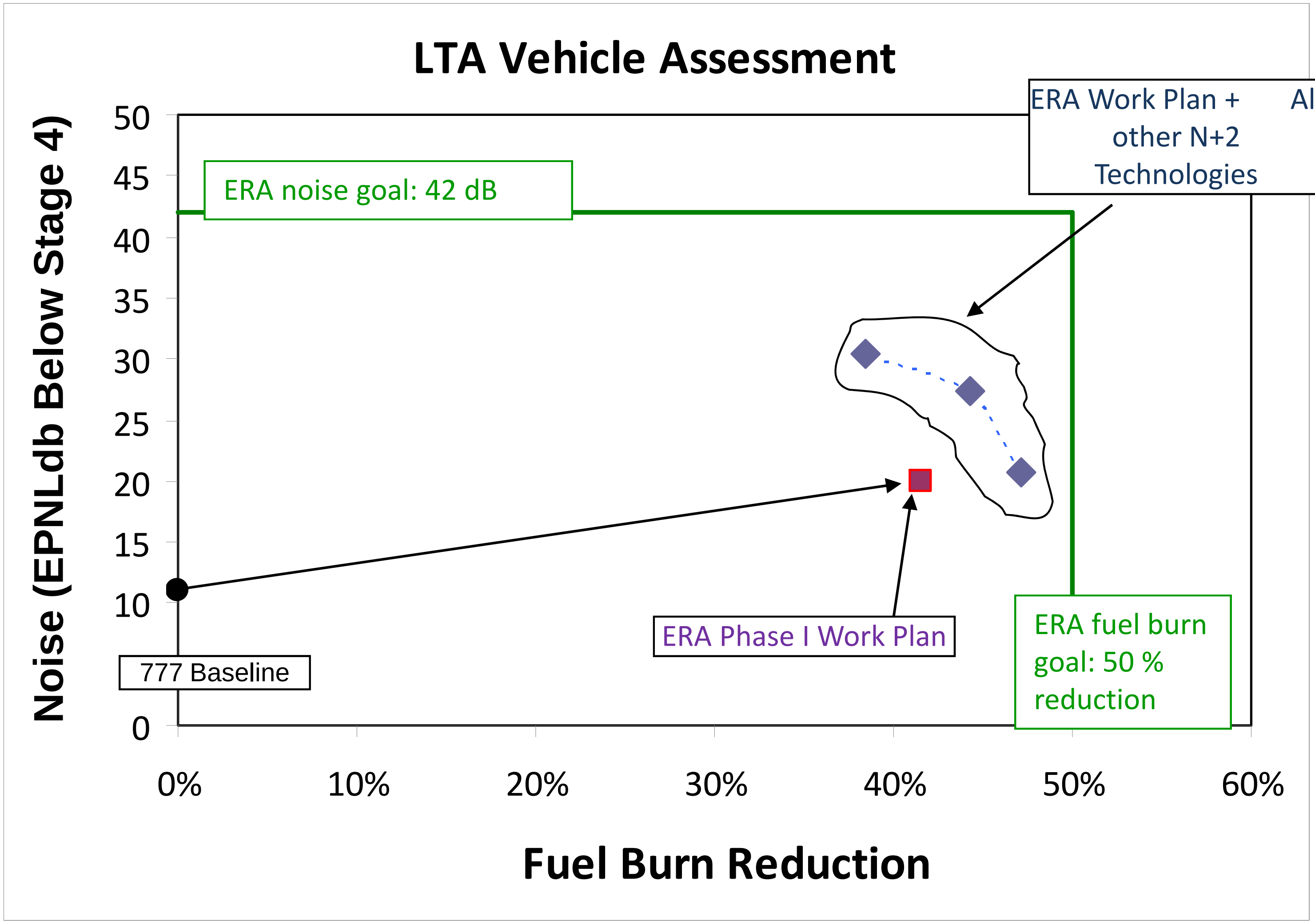
Concept Modeling Summary

	Regional Jet	Single Aisle	Small Twin Aisle	Large Twin Aisle	Very Large
Baseline Vehicle	CRJ900	737-800	767-300ER	777-200ER	747-400
Engine	CF34-8	CFM56-7B27	CF6-80	GE90-94B	PW4056
Passengers	86	174	210	301	416
2025 Tube+Wing					
Fuel Burn	-42.0%	-40.8%	-47.3%	-44.3%	-41.0%
Noise (dB cum below Stage 4)	30.5	24.0	27.1	27.3	22.6
Emissions	-75.0%	-75.0%	-75.0%	-75.0%	-75.0%
2025 HWB					
Fuel Burn	N/A	N/A	TBD	-50.2%	TBD
Noise (dB cum below Stage 4)	N/A	N/A	TBD	43.6	TBD
Emissions	N/A	N/A	TBD	-75.0%	TBD
2025 Concept X					
Fuel Burn					
Noise (dB cum below Stage 4)					
Emissions					

Trade Space Visualization
Advanced LTA Class Tube and Wing



Optimized Points Comparison to Goals
Advanced LTA Class Tube and Wing



***Key Takeaways*:**

1. **ERA Phase I Portfolio makes significant improvements in noise and fuel burn**

2. **ERA Phase I plan plus all potential N+2 technologies applied to advanced tube and wing will not meet the goal (noise / fuel burn tradeoff)**

3. **A configuration change is required (configuration itself is a technology) to meet the ERA goal.**

Noise / Fuel Burn Tradeoff

Best Technology Package – LTA Class T+W

Airframe Technologies

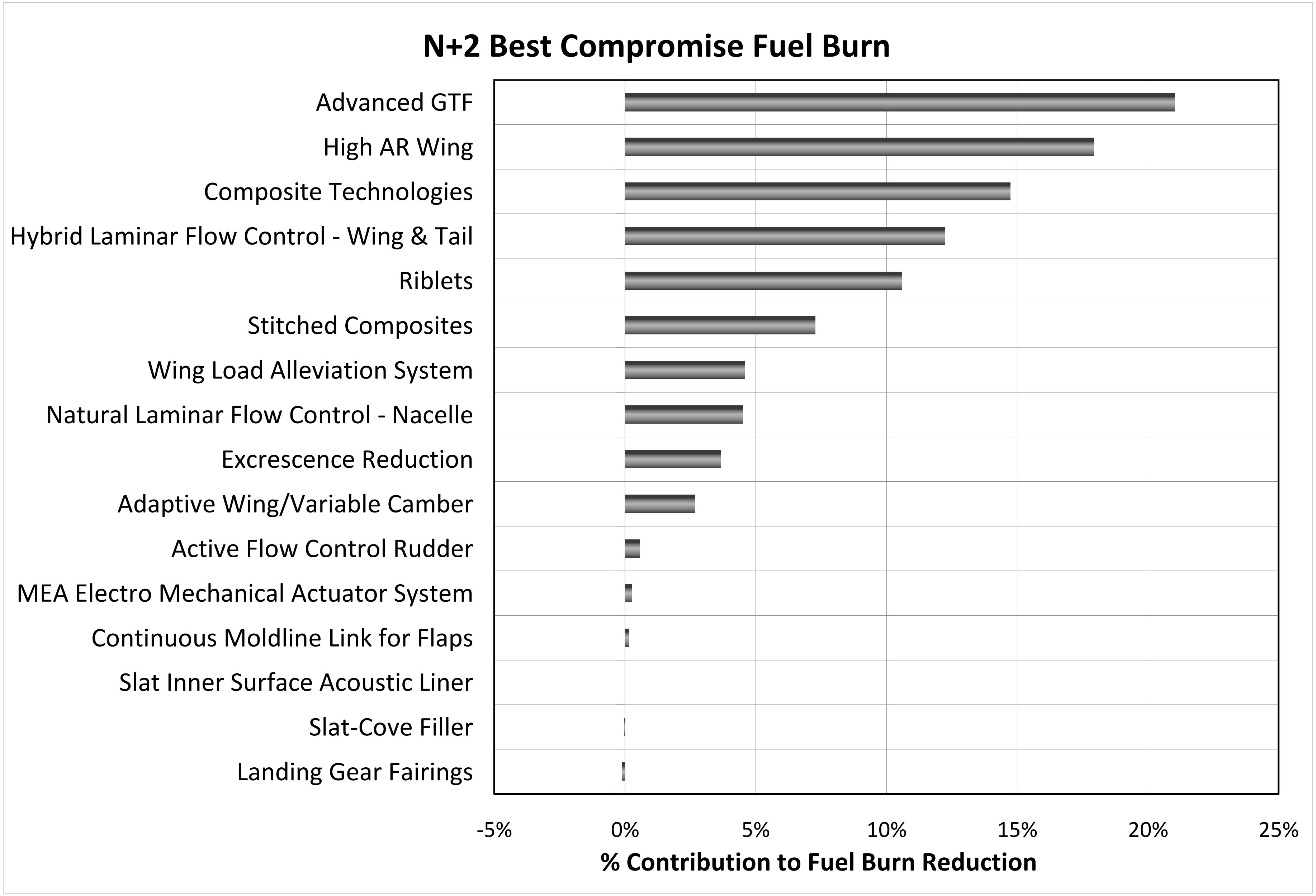
- Composite Material Technologies
- Stitched Composites/PRSEUS
- Wing Load Alleviation System
- M.E.A. Electro Mechanical Actuators
- Adaptive Wing - T.E. Variable Camber
- Excrescence Reduction
- HLFC - Wing and Tails
- NLF – Nacelles
- Riblets
- Active Flow Control Rudder
- Continuous Moldline Link for Flaps
- Landing Gear Fairings - Main/Nose
- Slat Inner Surface Acoustic Liner
- Slat-Cove Filler

Engine Technologies

- Active Compressor/Turbine Clearance Control
- Active Compressor/Turbine Flow Control
- Active Film Cooling
- Highly Loaded Compressor/Turbine
- Advanced TBC Coatings
- Advanced Turbine Nickel Based Superalloys
- Ceramic Matrix Composites
- High Temperature Erosion Coating for CMC
- Metal Matrix Composites
- Polymer Matrix Composites
- PMC Fan Blade with Metal Leading Edge
- PMC with High Temperature Erosion Coatings
- Beveled Nozzle
- Combustor Liner
- Herschel-Quincke Tube Liner Integration
- Long-cowl Nacelle Common Nozzle
- Lip Liner
- Over-the-Rotor Metal Foam Liner
- Rotor Sweep
- Soft Vane
- Stator Sweep and Lean
- Variable Geometry Chevrons
- Zero Splice Inlet
- Lightweight CMC Liner
- Advanced Combustor

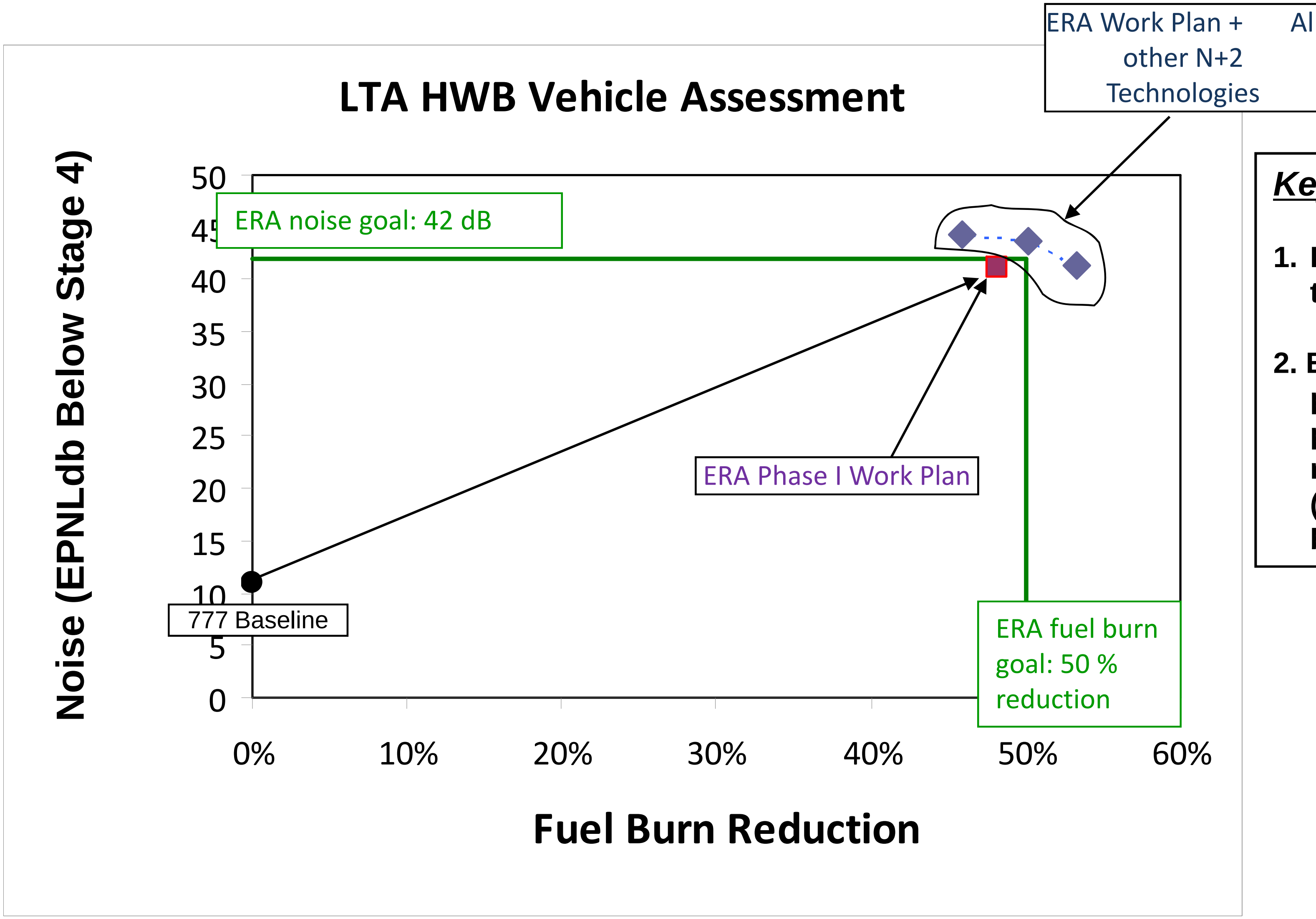
Green Font = ERA Phase I Technology

LTA Class Advanced T+W Rankings



Optimized Points Comparison to Goals

Advanced LTA Class HWB



***Key Takeaways*:**

1. **ERA Phase I Portfolio targeted at HWB**
2. **ERA Phase I plan plus all potential N+2 technologies plus HWB configuration will meet the ERA goal (noise+ fuel burn+emissions)**

Best Technology Package – LTA Class HWB

LTA HWB Airframe Technologies

Composite Material Technologies
Stitched Composites/PRSEUS
Wing Load Alleviation System
M.E.A. Electro Mechanical Actuators
Excrescence Reduction
HLFC - Wing
NLF – Nacelles
Riblets
Landing Gear Fairings - Main/Nose
Slat Inner Surface Acoustic Liner

LTA Engine Technologies

Active Compressor/Turbine Clearance Control
Active Compressor/Turbine Flow Control
Active Film Cooling
Highly Loaded Compressor/Turbine
Advanced TBC Coatings
Advanced Turbine Nickel Based Superalloys
Ceramic Matrix Composites
High Temperature Erosion Coating for CMC
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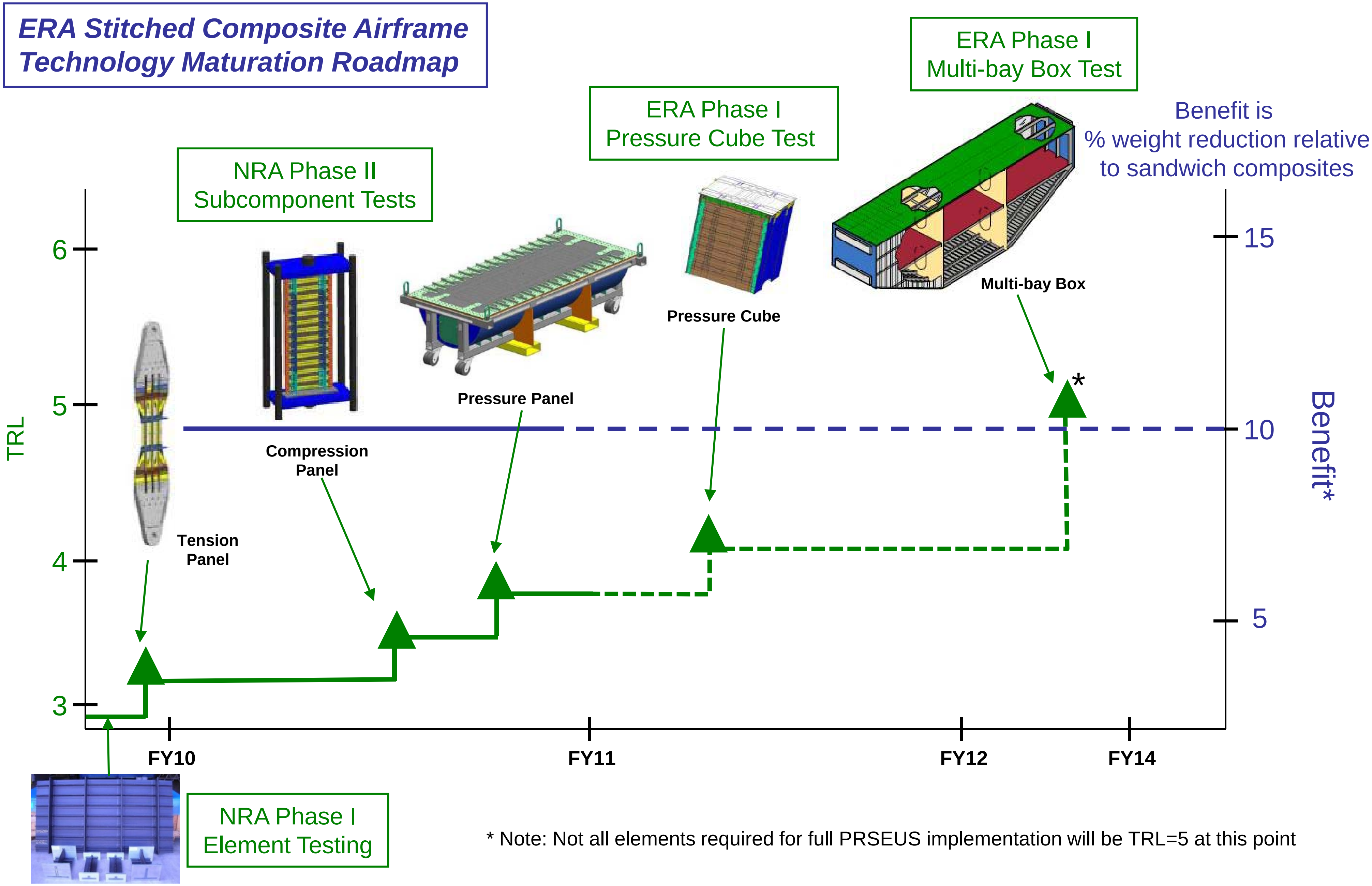
Over-the-Rotor Metal Foam Liner
Rotor Sweep
Soft Vane
Stator Sweep and Lean
Variable Geometry Chevrons
Zero Splice Inlet
Lightweight CMC Liner
Advanced Combustor

Green Font = ERA Phase I Technology

Measuring Progress from the "Bottom Up"

WBS: 2.1 Lightweight Structures
Technology: PRSEUS for the HWB Centerbody
Objective: Reduce primary structural weight

ERA Stitched Composite Airframe Technology Maturation Roadmap



* Note: Not all elements required for full PRSEUS implementation will be TRL=5 at this point

Questions?